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Application No. **09/941,780**

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Customer Name (Number): Fitzpatrick, Cella, Harper & Scinto - (5514)
Contact and Fax: Anthony Zupcic - (212)218-2240
Reviewer: Frank DeLucia

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FIG. 13

PRIOR ART

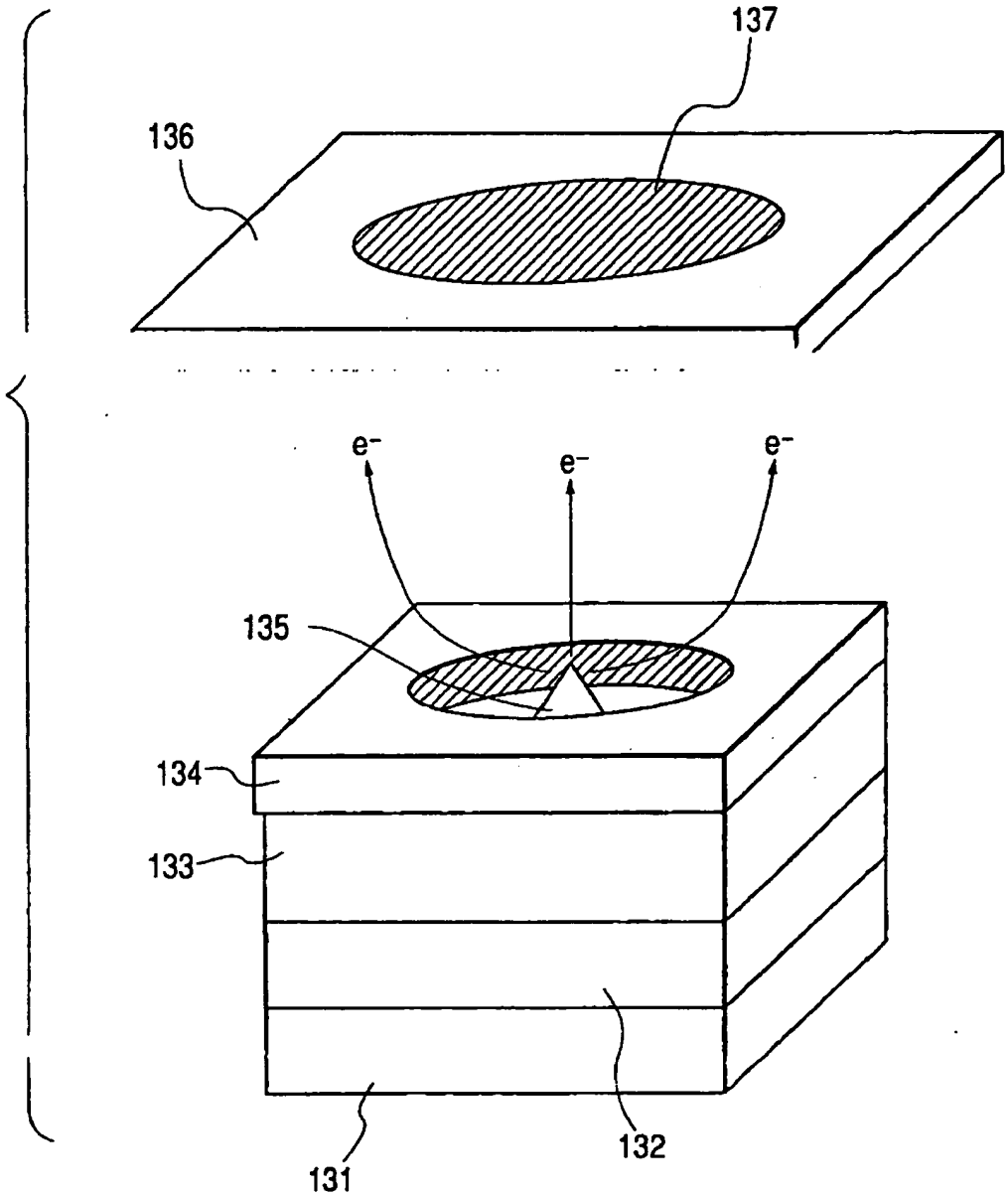
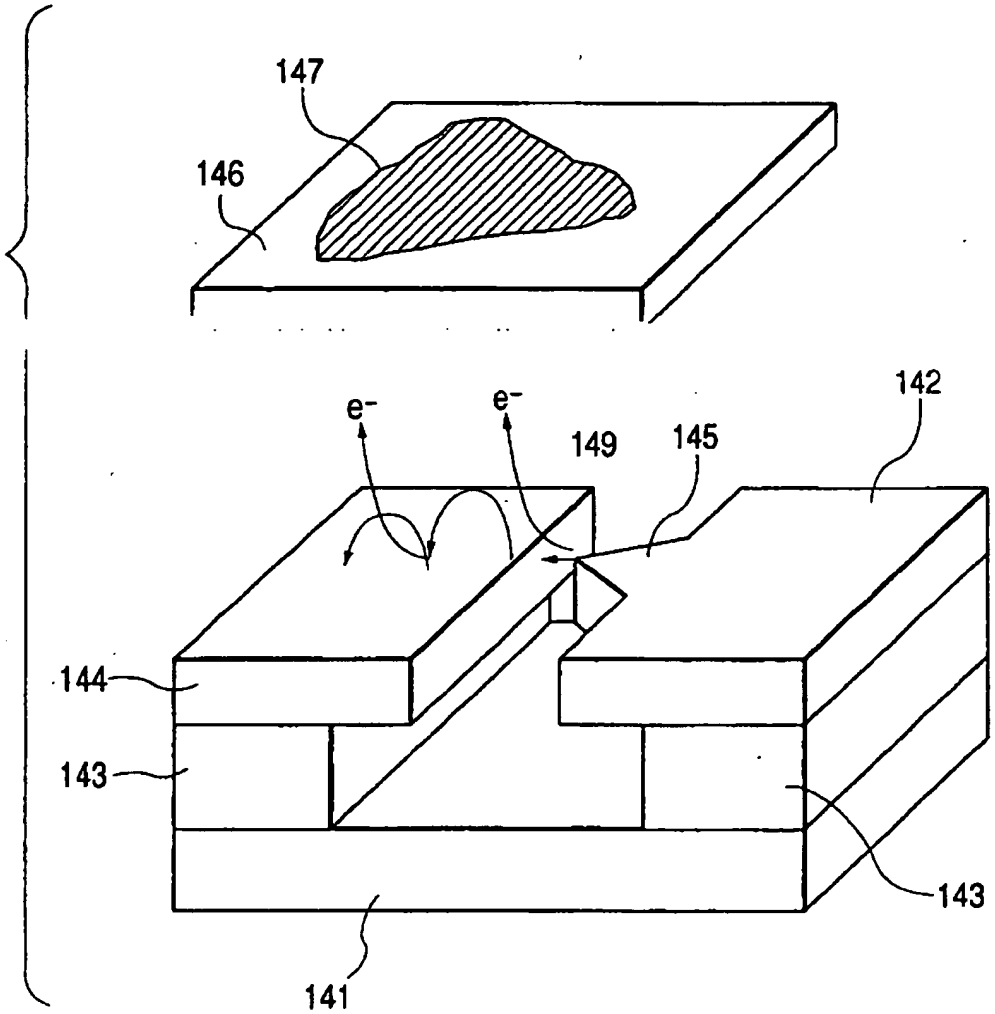


FIG. 14

PRIOR ART



electrodes by 132 and 142; insulating layers by 133 and 143; emitters by 135 and 145; anodes by 136 and 146; the shapes of electron beams with which the anodes are irradiated by 137 and 147.

In the case of the Spindt type described above with reference to FIG. 13, when Vf is applied between the emitter 135 and the gate 134, the strength of the electric field at the extreme end of the projection of the emitter 135 is increased and electrons are thereby taken out of a conical emitter portion about the extreme end into the vacuum.

The electric field at the extreme end of the emitter is formed based on the shape of the extreme end of the emitter to have a certain finite area on the same, so that electrons are perpendicularly drawn out from the finite emitter extreme end area according to the potential.

Simultaneously, other electrons are emitted at various angles. Electrons emitted at larger angles are necessarily drawn toward the gate.

As a result, if the gate is formed so as to have a circular opening, the distribution of electrons on the anode 136 shown in FIG. 13 forms a substantially circular beam shape 137. That is, the shape of the beam obtained is closely related to the shape of the drawing gate and to the distance between the gate and the emitter.

In the case of the lateral FE electron source (FIG. 14) in which electrons are drawn out generally along one direction, an extremely strong electric field substantially parallel to the surface of the substrate 141 (lateral electric field) is produced between the emitter 145 and the gate 144, so that part 149 of electrons emitted from the emitter 145 are drawn into the vacuum above the gate 144 while the other electrons are taken into the gate electrode 144.

In the arrangement shown in FIG. 14, electric field vectors toward the anode 146 differ in direction from those causing emission of electrons (the electric field from the emitter 145 toward the gate 144). Therefore the distribution of electrons (beam spot) formed by emitted electrons on the anode 146 is increased.

The electric field of electrons drawn out from the emitter electrode 145 (referred to as "lateral electric field" in the following description for convenience sake while the electric field strengthening effect of the emitter configuration is ignored) and the electric field toward the anode (referred to as "vertical electric field" in the following description) will further be described.

The "lateral electric field" can also be expressed as "electric field in a direction substantially parallel to the surface of substrate 131 (141)" in the arrangement shown in FIG. 13 or 14. It can also be expressed as "electric field in the direction of opposition of gate 144 and emitter 145" with respect to the arrangement shown in FIG. 14 in particular.

Also, the "vertical electric field" can also be expressed as "electric field in a direction substantially perpendicular to the surface of substrate 131 (141)" in the arrangement shown in FIG. 13 or 14, or as "electric field in the direction in which the substrate 131 (141) is opposed to the anode 136 (146)".

In the arrangement shown in FIG. 14, as described above, electrons emitted from the emitter are first drawn out by the lateral electric field, fly toward the gate, and are then moved upward by the vertical electric field to reach the anode.

Important factors of this effect are the ratio of the strengths of the lateral and vertical electric fields and the relative position of the electron emission point.

When the lateral electric field is stronger than the vertical electric field by an order of magnitude, the trajectories of almost all of electrons drawn out from the emitter are gradually bent by radial potential produced by the lateral electric field so that the electrons fly toward the gate. A part of the electrons impinging on the gate ejects again in a scattering manner. After ejection, however, the electrons repeat scattering while spreading out along the gate by forming elliptical trajectories again and again and while being reduced in number when ejecting until they are caught by the vertical electric field. Only after the scattered electrons have exceeded an equipotential line formed by the gate potential (which line may be called "stagnation point"), they are moved upward by the vertical electric field.

When the lateral electric field and the vertical electric field are approximately equal in strength, the restraint imposed by the lateral electric field on electrons drawn out is reduced, although the trajectories of the electrons are bent by the radial potential. In this case, therefore, electron trajectories appear along which electrons travel to be caught by the vertical electric field without impinging on the gate.

It has been found that if the electron emission position at which electrons are emitted from the emitter is shifted from the gate plane toward the anode plane (see FIG. 6), emitted electrons can form trajectories such as to be caught by the vertical electric field with substantially no possibility of impinging on the gate when the lateral electric field and the vertical electric field are approximately equal in strength, that is, the ratio of the strength of the lateral electric field to that of the vertical electric field is approximately 1 to 1.

Also, a study made of the electric field ratio has shown that if the distance between the gate electrode 144 and the extreme end of the emitter electrode 145 is d; the potential difference (between the gate electrode and the emitter electrode) when the device is driven is V1; the distance between the anode and the substrate (element) is H; and the potential difference between the anode and the cathode (emitter electrode) is V2, a trajectory along which electrons drawn out impinge on the gate is formed when the lateral electric field E1=V1/d is 50 times or more stronger than the vertical electric field E2=V2/H.

The inventor of the present invention has also found that a height s (defined as the distance between a plane containing a portion of a gate electrode 2 surface and substantially parallel to a substrate 1 surface and a plane containing an electron-emitting member 4 surface and substantially parallel to the substrate 1 surface (see FIG. 6)) can be determined such that substantially no scattering occurs on the gate electrode 2. The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric field strength/lateral electric field strength). As the vertical-lateral electric field ratio is lower, the height s is lower. AS the lateral electric field is stronger, the necessary height s is higher.

The height set in a practical manufacturing process ranges from 10 nm to 10 μm.

In the conventional arrangement shown in FIG. 14, the gate 144 and the emitter (142, 145) are formed flush with each other along a common plane and the lateral electric field is stronger than the vertical electric field by an order of magnitude, so that there is a considerable tendency to reduce, by impingement on the gate, the amount of electrons drawn out into the vacuum.

Further, in the conventional arrangement, the structure of the device is determined so as to increase the strength of the electric field in the lateral direction, so that the electron distribution on the anode 146 spreads widely.

As described above, to restrict the distribution of electrons reaching the anode 146, it is necessary (1) to reduce the

growth in chemical vapor deposition (CVD). In the case of RIE, the control of the emitter shape depends on the kind of the substrate used, the kind of gas, the gas pressure (flow rate), the etching time, the energy for forming plasma, etc. In a CVD forming process, the emitter shape is controlled by selecting the kind of the substrate, the kind of gas, the flow rate, the growth temperature, etc.

Examples of the material used to form the emitter (electron-emitting member) 4 are carbides, such as TiC, ZrC, HfC, TaC, SiC, and WC, amorphous carbon, graphite, diamondlike carbon, carbon containing dispersed diamond, and carbon compounds.

invention,

According to the present intention, fibrous carbon is particularly preferably used as the material of the emitter (electron-emitting member) 4. "Fibrous carbon" referred to in the description of the present invention can also be expressed as "material in columnar form containing carbon as a main constituent" or "material in filament form containing carbon as a main constituent". Further, "fibrous carbon" can also be expressed as "fibers containing carbon as a main constituent". More specifically, "fibrous carbon" in accordance with the present invention comprises carbon nanotubes, graphite nanofibers, and amorphous carbon fibers. In particular, graphite nanofibers are most preferred as electron-emitting member 4.

The gap between the extraction electrode 2 and the cathode 3 and the drive voltage (the voltage applied between the extraction electrode 2 and the cathode 3) may be determined so that the value of the lateral electric field necessary for emission of electrons from the cathode material used is 1 to 50 times larger than that of the vertical electric field necessary for forming an image, as described above.

In a case where a light-emitting member such as a phosphor is provided on the anode, the necessary vertical electric field is, preferably, within the 10^{-1} to 10 V/μm range. For example, in a case where the gap between the anode and the cathode is 2 mm and 10 kV is applied between the anode and the cathode, the vertical electric field is 5 V/μm. In this case, the emitter material (electron-emitting member) 4 to be used has an electron-emitting electric field value of 5 V/μm or higher. The gap and the drive voltage may be determined in correspondence with the selected electron-emitting electric field value.

An example of a material having an electric field threshold of several V/μm is fibrous carbon. Each of FIGS. 11 and 12 shows an example of the configuration of fibrous carbon. In each of FIGS. 11 and 12, the configuration is schematically shown at the optical microscope level (to 1,000 times) in the left-hand section, at the scanning electron microscope level (to 30,000 times) in the middle section, and at the transmission electron microscope level (to 1,000,000 times) in the right-hand section.

A graphene structure formed into a cylinder such as that shown in FIG. 11 is called a carbon nanotube (a multilayer cylindrical graphene structure is called a multiwall nanotube). Its threshold value is minimized when the tube end is opened.

The fibrous carbon shown in FIG. 12 may be produced at a comparatively low temperature. Fibrous carbon having such a configuration is composed of a graphene layered body (thus, it may be referred to as "graphite nanofiber", and has an amorphous structure whose ratio is increased with temperature). More specifically, "graphite nanofiber" designates a fibrous substance in which graphenes are layered (laminated) in the longitudinal direction thereof (in the axis direction of the fiber). In other words, graphite nanofiber is a fibrous substance in which a plurality of graphenes are arranged and layered (laminated) so as not to be parallel to the fiber axis, as shown in FIG. 12.

On the other hand, a carbon nanotube is a fibrous substance in which graphenes are arranged (in cylindrical shape) around the longitudinal direction (fiber axis direction). In other words, it is a fibrous substance in which graphenes are arranged substantially parallel to the fiber axis.

One layer of graphite is called "graphene" or "graphene sheet". More specifically, graphite is formed in such a manner that carbon planes on which carbon atoms are arrayed so as to form regular hexagons close to each other by covalent bond in sp^2 hybridization are laid one on another while being spaced by a distance of 3.354 Å. Each carbon plane is called "graphene" or "graphene sheet".

Each type of fibrous carbon has an electron emission threshold value of about 1 to 10 V/μm and is therefore preferred as the material of the emitter (electron-emitting member) 4 in accordance with the present invention.

In particular, electron-emitting devices using graphite nanofibers, not limited to the device structure of the present invention shown in FIG. 1, etc., are capable of causing emission of electrons in a low electric field to obtain a large emission current, and can be readily manufactured to obtain as an electron-emitting device having stable electron-emitting characteristics. For example, such an electron-emitting element can be obtained by forming graphite nanofibers as an emitter and by providing an electrode for controlling emission of electrons from the emitter. Further, if a light emitting member capable of emitting light when irradiated with electrons emitted from graphite nanofibers is used, a light emitting device such as a lamp can be formed. Further, an image display apparatus may be constructed by forming an array of a plurality of the above-described electron-emitting devices and by preparing an anode having a light emitting material such as a phosphor. In the electron-emitting device, the light emitting device or the image display apparatus using above-described graphite nanofibers, stable emission of electrons can be achieved without maintaining inside the device or the apparatus an ultrahigh vacuum such as that required in conventional electron-emitting devices. Moreover, since electrons are emitted by a low electric field, the device or apparatus can be easily manufactured with improved reliability.

The above-described fibrous carbon can be formed by decomposing a hydrocarbon gas by using a catalyst (a material for accelerating deposition of carbon). The processes for forming carbon nanotubes and graphite nanofibers differ in the kind of catalyst and decomposition temperature.

The catalytic material may be a material which is used as a seed for forming fibrous carbon, and which is selected from Fe, Co, Pd, No, and alloys of some of these materials.

In particular, if Pd or Ni is used, graphite nanofibers can be formed at a low temperature (not lower than 400° C.). The necessary carbon nanotube forming temperature in the case of using Fe or Co is 800° C. or higher. Also, the process of producing a graphite nanofiber material by using Pd or Ni, which can be performed at a lower temperature, is preferred from the viewpoint of reducing the influence on other components and limiting the manufacturing cost.

Further, the characteristic of Pd that resides in enabling oxides to be reduced by hydrogen at a low temperature (room temperature) may be utilized. That is, palladium oxide may be used as a seed forming material.

The envelop 97, as described above, is constituted by the face plate 96, the supporting frame 92, and the rear plate 91. The rear plate 91 is provided mainly for the purpose of reinforcing the substrate 81. If the substrate 81 itself has sufficiently high strength, there is no need to separately provide the rear plate 91. That is, the supporting frame 92 may be directly seal-bonded to the substrate 81 and the envelop 97 may be formed by the frame plate 96, the supporting frame 92 and the substrate 81. A supporting member (not shown) called a spacer may be provided between the face plate 96 and the rear plate 91 to enable the envelop 97 to have a sufficiently high strength for resisting atmospheric pressure.

Embodiments of the present invention will be described below in detail.

(Embodiment 1)

FIG. 1A shows a top view of an electron-emitting device fabricated in this embodiment. FIG. 1B is a cross-sectional view taken along the line 1B—1B of FIG. 1A.

FIGS. 1A and 1B illustrate an insulating substrate 1, an extraction electrode 2 (gate), a cathode 3, and an emitter material 4.

The process of fabricating the electron-emitting device of this embodiment will be described in detail.

(Step 1)

A quartz substrate was used as substrate 1. After sufficiently cleansing the substrate, a 5 nm thick Ti film (not shown) and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the substrate as gate electrode 2 and cathode 3.

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

Thereafter, dry etching was performed on the poly-Si (arsenic doped) layer and Ti layer with the patterned photoresist used as a mask, CF_4 gas being used to etch the Ti layer. An extraction electrode 2 and a cathode 3 having a gap of 5 μm therebetween were thereby formed (FIG. 5A).

(Step 2)

Next, a Cr having a thickness of about 100 nm was deposited on the entire substrate by electron beam (EB) evaporation.

A resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

An opening corresponding to a region (100 μm square) where electron-emitting material 4 was to be provided was formed on the cathode 3 with the patterned photoresist used as a mask. Cr at the opening was removed by using a cerium nitrate etching solution.

After removing the resist, a complex solution prepared by adding isopropyl alcohol, etc., to a Pd complex was applied to the entire substrate by spin coating.

After application of the solution, a heat treatment was performed in atmospheric air at 300° C. to form a palladium oxide layer 51 having a thickness of about 10 nm. Thereafter, Cr was removed by using a cerium nitrate etching solution (FIG. 5B).

(Step 3)

The substrate was baked at 200° C., atmospheric air was evacuated, and a heat treatment was then performed in 2% hydrogen flow diluted with nitrogen. At this stage, particles 52 having a diameter of about 3 to 10 nm were formed on the surface of the cathode 3. The density of the particles at this stage was estimated at about 10^{11} to 10^{12} particles/cm^2 (FIG. 5C).

(Step 4)

Subsequently, a heat treatment was performed in a 0.1% ethylene flow diluted with nitrogen at 500° C. for 10 minutes. The state after the heat treatment was observed with a scanning electron microscope to find that a multiplicity of fibrous carbon 4 having a diameter of about 10 to 25 nm and extending like fibers while curving or bending had been formed in the Pd-coated region. The thickness of the fibrous carbon layer was about 500 nm (FIG. 5D).

This electron-emitting device was set in the vacuum apparatus 60 shown in FIG. 6. A sufficiently high vacuum of about 2×10^{-5} Pa was produced by the evacuating pump 62. Voltage Va=10 kV was applied as anode voltage to the anode 61 distanced by H=2 mm from the device, as shown in FIG. 6. Also, a pulse voltage of Vf=20 V was applied as drive voltage to the device. Device current If and electron emission current Ie thereby caused were measured.

The If and Ie characteristics of the electron-emitting device were as shown in FIG. 7. That is, Ie rises abruptly at a voltage about half the applied voltage, and a current of about 1 μA was measured as electron emission current Ie at a Vf value of 15 V. On the other hand, the If characteristic was similar to the Ie characteristic but the value of If was smaller than that of Ie by an order of magnitude or more.

The obtained beam had a generally rectangular shape having a longer side along the Y-direction and a shorter side in the X-direction. The beam width was measured with respect to different gaps of 1 μm and 5 μm between the electrodes 2 and 3 while Vf was fixed at 15 V and the distance H to the anode was fixed at 2 mm. Table 1 shows the results of this measurement.

TABLE 1

	Va = 5 kV	Va = 10 kV
Gap: 1 μm	60 μm in x-direction 170 μm in y-direction	30 μm in x-direction 150 μm in y-direction
Gap: 5 μm	93 μm in x-direction 170 μm in y-direction	72 μm in x-direction 150 μm in y-direction

It was possible to change the necessary electric field for driving by changing the fibrous carbon growth conditions. In particular, the average particle size of Pd particles formed by reduction of palladium oxide is related to the diameter of fibrous carbon thereafter grown. It was possible to control the average Pd particle size through the Pd density in the Pd complex coating and the rotational speed of spin coating.

The fibrous carbon of this electron-emitting device was observed with the transmission electron microscope to recognize a structure in which graphenes are layered in the fiber axis direction, as shown in the right-hand section of FIG. 12. The graphene stacking intervals (in the Z-axis direction) resulting from heating at a lower temperature, about 500° C. were indefinite and was 0.4 nm. As the heating temperature was increased, the grating intervals became definite. The intervals resulting from heating at 700° C. were 0.34 nm, which is close to 0.335 nm in graphite.

(Embodiment 2)

FIG. 2 shows a second embodiment of the present invention.

In this embodiment, an electron-emitting device was fabricated in the same manner as that in the first embodiment except that the cathode 3 corresponding to that in the first embodiment had a thickness of 500 nm and fibrous carbon provided as electron-emitting material 4 had a thickness of 100 nm. Currents If and Ie in the fabricated electron-emitting device were measured.

In this device arrangement, the electron emission point was positively heightened (toward the anode) relative to the gate electrode by increasing the thickness of the cathode 3.

Trajectories along which electrons impinge on the gate were thereby reduced, thereby preventing a reduction in efficiency and occurrence of a beam-thickening phenomenon.

Also in this device arrangement, the electron emission current Ie at Vf=20V was about 1 μA. On the other hand, the If characteristic was similar to the Ie characteristic but the value of If was smaller than that of Ie by two orders of magnitude.

The results of measurement of the beam diameter in this embodiment were substantially the same as those shown in Table 1.

(Embodiment 3)

FIG. 3 shows a third embodiment of the present invention.

In this embodiment, in the step corresponding to step 2 in the first embodiment, palladium oxide 51 was provided on the cathode 3 and in the gap between the electrodes 2 and 3. Pd oxide was provided in the gap in such a manner as to extend from the cathode 3 to a point near the midpoint of the gap. Excepting step 2, this embodiment is the same as the first embodiment.

The electric field in the electron-emitting device of this embodiment was twice as strong as that in the first embodiment because the gap was reduced, thereby enabling the drive voltage to be reduced to about 8 V.

(Embodiment 4)

FIG. 4 shows a fourth embodiment of the present invention. In this embodiment step 1 and step 2 described above with respect to the first embodiment are changed as described below.

(Step 1)

A quartz substrate was used as substrate 1. After sufficiently cleansing the substrate, a 5 nm thick Ti film and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the substrate as cathode 3.

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

Next, dry etching was performed on the poly-Si layer and Ti layer by using CF_4 gas, with the patterned photoresist used as a mask. Cathode 3 was thereby formed.

The quartz substrate was then etched to a depth of about 500 nm by using a mixed acid formed of hydrofluoric acid and ammonium fluoride.

Subsequently, a 5 nm thick Ti film and a 30 nm thick Pt film were successively deposited on the substrate as gate electrode 2 by again performing sputtering. After removing the photoresist from the cathode, a resist pattern was again formed by using a positive photoresist (AZ1500/ from Clariant Corporation) to form the gate electrode.

Next, dry etching was performed on the Pt layer and Ti layer by using Ar, with the patterned photoresist used as a mask. Electrode 2 was thereby formed so that the step formed between the electrodes functions as a gap.

Next, a resist pattern was formed on the cathode, a Ni film having a thickness of about 5 nm was formed by resistance heating evaporation having a good straight-in effect, and oxidation was thereafter performed at 350° C. for 30 minutes.

This step was followed by the same steps as those in the first embodiment.

The above-described device arrangement enabled formation of a finer gap such that electrons were effectively emitted at a lower voltage of about 6 V.

Because the height of the electron-emitting material 4 (film thickness) was increased relative to that of the gate electrode, electrons were drawn out not only from the upper portion of the electron-emitting material 4 but also from an intermediate portion. Thus, the arrangement in this embodiment has the effect of preventing a reduction in efficiency due to impingement of electrons on the gate electrode and occurrence of a beam-thickening phenomenon.

(Embodiment 5)

An electron source obtained by arranging a plurality of the electron-emitting devices fabricated the first embodiment and an image forming apparatus using this electron source will be described with reference to FIGS. 8, 9, and 10. In FIG. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting devices 84 in accordance with the present invention, and connecting conductors 85.

The electron source with matrix wiring shown in FIG. 8, in which the device capacitance is increased by arranging a plurality of electron-emitting devices, has a problem that, even when a short pulse produced by pulse-width modulation is applied, the waveform is dulled or distorted by capacitive components to cause failure to obtain the necessary grayscale level, for example. In this embodiment, therefore, a structure is adopted in which an interlayer insulating layer is provided by the side of the electron-emitting region to limit the increase in capacitive components in regions other than the electron-emitting region.

Referring to FIG. 8, X-direction wiring 82 has m conductors DX1, DX2, ... DXm, which has a thickness of about 1 μm and a width of 300 μm, and which is formed of an aluminum wiring material by evaporation. The material, film thickness, and width of the wiring conductors are selected according to a suitable design. Y-direction wiring 83 has n conductors DY1, DY2, ... DYn, which has a thickness of 5 μm and width of 100 μm, and which is formed in the same manner as X-direction wiring 82. An interlayer insulating layer (not shown) is provided between the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 to electrically separate these conductors (each of m and n is a positive integer).

The interlayer insulating layer (not shown) is, for example, a SiO_2 layer formed by sputtering or the like and having a thickness of about 0.8 μm. For example, the interlayer insulating film is formed in the desired shape over the whole or part of the surface of the substrate 81 on which X-direction wiring 82 has been formed. Specifically, the thickness of the interlayer insulating film is determined so as to ensure withstanding against the potential difference at the intersections of the conductors of X-direction wiring 82 and Y-direction wiring 83. The conductors of X-direction wiring 82 and Y-direction wiring 83 are respectively extended outward as external terminals.

Pairs of electrodes (not shown) constituting electron-emitting devices 84 are electrically connected to the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 by connecting conductors 85 made of a conductive metal or the like.

A scanning signal application means (not shown) for applying scanning signals for selecting the rows of electron-emitting devices 84 arranged in the X-direction is connected to X-direction wiring 82. On the other hand, a modulation signal generation means for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage corresponding to the difference between the scanning signal and the modulation signal applied to the element. In the present invention, Y-direction wiring 83 is connected to the gate electrodes 2 of the electron-emitting devices described

21. An electron-emitting apparatus comprising:

A) a first electrode and a second electrode disposed on a surface of a substrate;

B) first voltage application means for applying to said second electrode a potential higher than a potential applied to said first electrode;

C) a plurality of fibers disposed on said first electrode, said fibers containing carbon as a main constituent;

D) a third electrode disposed so as to face said substrate, electrons emitted from said fibers reaching said third electrode; and

E) second voltage application means for applying to said third electrode a potential higher than each of the potentials applied to said first and second electrodes,

wherein a surface region of said fibers is placed between a plane containing a surface of said second electrode and substantially parallel to the surface of said substrate and a plane containing a surface of said third electrode and substantially parallel to the surface of said substrate.

22. An electron-emitting apparatus according to claim 21, wherein when the distance between said second electrode and said first electrode is d; the potential difference applied between said second electrode and said first electrode by said first voltage application means is V1; the distance between said third electrode and said substrate is H; and the potential difference between the potential applied to said third electrode by said second voltage application means and the potential applied to said first electrode is V2, then an electric field E1=V1/d is within the range from 1 to 50 times an electric field E2=V2/H.

23. An apparatus according to claim 21, wherein each of said fibers having carbon as a main ingredient comprises a carbon nanotube.

24. An apparatus according to claim 21, wherein each of said fibers containing carbon as a main ingredient comprises a plurality of graphenes stacked so as to be nonparallel to the axis direction of said fiber.

25. An apparatus according to claim 21, wherein a material more effective in accelerating deposition of carbon than the material of said first electrode is provided between said fibers having carbon as a main ingredient and said cathode.

26. An apparatus according to claim 25, wherein said material effective in accelerating deposition of carbon comprises Pd, Ni, Fe, Co or an alloy formed of at least two of said metals.

27. An apparatus according to claim 25, wherein said material effective in accelerating deposition of carbon is provided in the form of a plurality of particles on said first electrode.

28. An apparatus according to claim 27, wherein said plurality of particles are provided on said first electrode at a density of 10^{10} particles/cm^2 or higher.

29. An apparatus according to claim 21, wherein the thickness of said first electrode is larger than the thickness of said second electrode.

30. An apparatus according to any one of claims 21 to 29, wherein a plurality of said first electrodes and a plurality of said second electrodes are disposed on the surface of said substrate.

31. An apparatus according to claim 30, wherein said plurality of first electrodes and said plurality of second electrodes are electrically connected to wiring in matrix form.

32. An apparatus according to claim 30, wherein a phosphor capable of emitting light when irradiated with electrons emitted from said fibers is provided on said third electrode.

33. An image display apparatus using an electron-emitting apparatus according to claim 32.

34. An electron-emitting device comprising:

A) a first electrode and a second electode disposed on a surface of a substrate, a gap being formed between said first and second electrodes; and

B) a fiber provided on said first electrode, said fiber containing carbon as a main ingredient,

wherein said second electrode comprises an electrode for controlling emission of electrodes from said fiber containing carbon as a main ingredient, and

wherein said fiber containing carbon as a main ingredient comprises graphene.

electrode

35. An electron-emitting device according to claim 34, wherein the distance between an extreme end of said fiber and the surface of said substrate is larger than the distance between the surface of said second electrode and the surface of said substrate.

36. An electron-emitting device according to claim 34, wherein said graphene comprises cylindrical graphene.

37. An electron-emitting device according to claim 34, wherein said electron-emitting device comprises a plurality of fibers containing carbon as a main ingredient.

38. A light-emitting apparatus comprising an electron-emitting device according to any one of claims 34 to 37, and a light-emitting member.

39. An image display apparatus comprising a plurality of electron-emitting devices and a light emitting member capable of emitting light when irradiated with electrons emitted from some of said plurality of electron-emitting devices, wherein each of said plurality of electron-emitting devices is constituted by an electron-emitting device according to any one of claims 34 to 37.

* * * * *